$98 per day). The greatest receipt for a single day has been $221. The expenses for a whole year have been:

For salaries, etc.	(about)	$13,380
" supplies, etc.	"	6,549
" advertisements, etc.	"	2,372
In all	(about)	$22,301

The journal, *Himmel und Erde*, has at present 1,500 paying subscribers, and has cost some $3,800 more than the receipts from subscribers. It has rendered most valuable service to science, not only by its important articles, but also by its capital reproductions of astronomical and other drawings and photographs. In this direction it has already conquered an absolutely unique position.

The foregoing statistics speak eloquently of the immense usefulness of this popular astronomical institute in its very varied relations, and the splendid success of its first year's work is a promise for its continued prosperity in the future. The benefits which such an establishment confers are manifold and far-reaching—from instruction to thousands of pupils in the schools up to opportunities of research in many branches afforded to skilled scientists. It is to be hoped that the brilliant success of *Gesellschaft Urania* may lead to the establishment of similar institutions in the different countries of Europe and of America. Fixed observatories already established can do no more useful work than by co-operating with such popular institutions in the fullest manner. E. S. H.

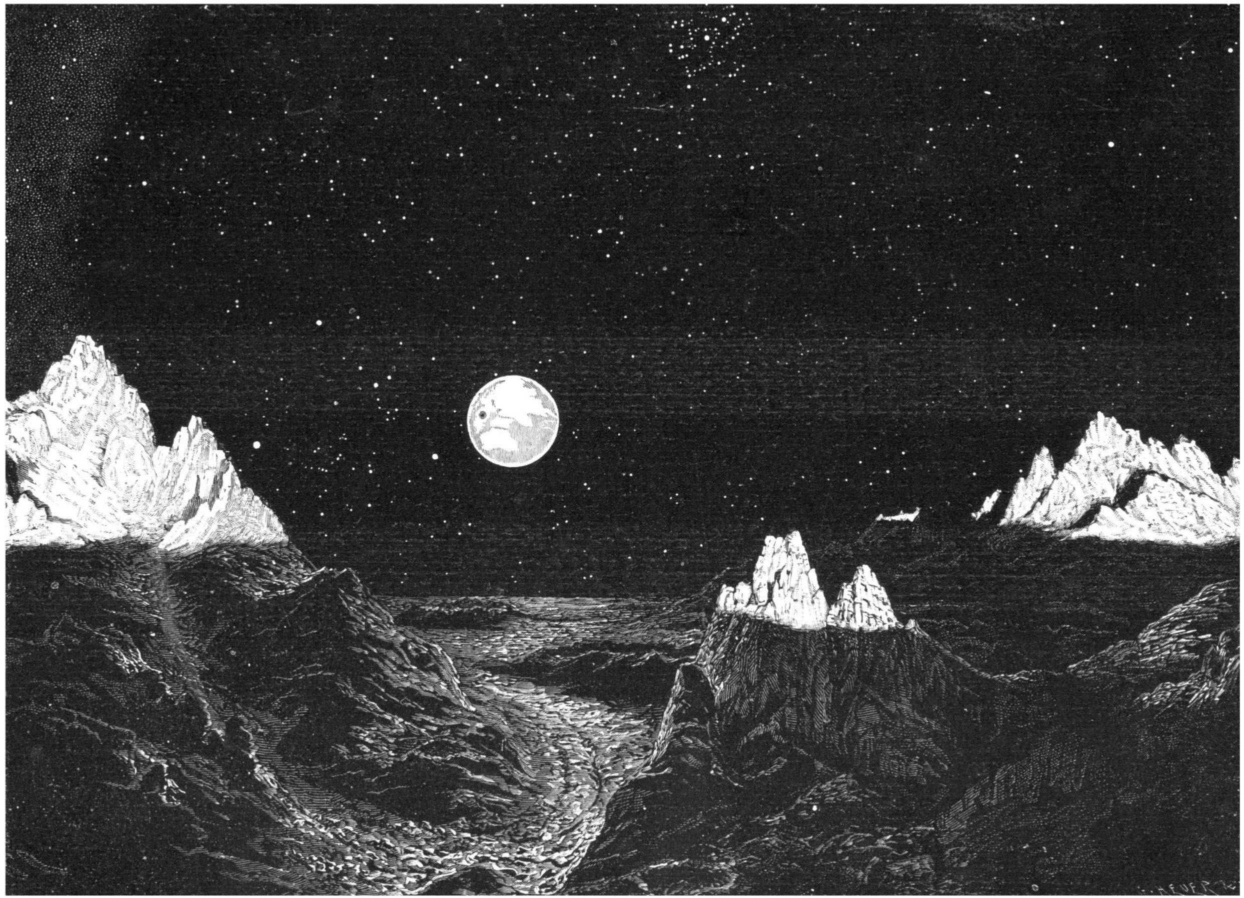
ASTRONOMICAL PHOTOGRAPHY AT THE LICK OBSERVATORY.*

By Edward S. Holden.

The editors of the *International Annual* have kindly asked me for an account of our photographic work at the Lick Observatory, and although (for reasons not necessary to state here) our work of this kind has but just begun, I am very glad to comply with their request, and to give very briefly our experience up to this time.

The experiments so far made indicate that the photographic lens (thirty-three inches aperture, 570 inches focus) will be found as satisfactory as the visual objective, thirty-six inches aperture, 694 inches focus. Both of these were made by Alvan Clark & Sons. The mounting of the great telescope is by Warner & Swasey of Cleveland, and this also has proved to be very satisfactory. The dome of seventy-five feet diameter (made by the Union Iron Works of San Francisco), with its elevating floor (sixty-one feet in diameter),

* Reprinted (with additions) from the *International Annual of Anthony's Photographic Bulletin, 1890.*



Solar Eclipse on the Earth, seen from the Moon.

has worked well, and the latter has proved itself to be almost essential in photographic operations with so great a telescope.

A number of subjects have hardly been touched at all, such as the photography of planets and direct enlargement; and the various difficulties in our other work are not yet all conquered, or even understood, but enough has been done to show that success can be attained. The observatory is very fortunate in counting among its astronomers Messrs. Burnham and Barnard, whose photographic skill and experience is equal to their astronomical ability. The other astronomers engage in the work of exposing and measuring the negatives, but all the photographic work proper has been done by these gentlemen in addition to their other duties.

Photographs of Stars.

In astronomical photography of stars we may have different objects in view. We may wish for a picture of the stars merely; or to measure their distances apart; or, finally, to determine their photographic brightness. The stars may be photographed as *dots* (*i. e.*, with the telescope driven by clock-work to follow the stars in their courses from rising towards setting) or as trails (the stars moving across the stationary plate from east towards west). In the first case (dots), we secure the impressions of fainter and fainter stars, according as the exposure is longer and longer. In the second case, we shall have no trails from the fainter stars, on account of the short exposure. With the great telescope a star on the equator moves $\frac{45}{1000}$ of an inch on the plate in one second of time, and $2\frac{7}{10}$ inches in one minute of time. Hence, only the brighter stars (about 7th magnitude or so) register their trails at the equator. The stars near the pole move very much slower, and stars of the 13th or 14th magnitude will trail.

To obtain star pictures or maps, long exposures are necessary with any telescope. If the instrument is intended to register the greatest possible number of stars, it should have a focus relatively short. Refractors with a double objective, on the model of a portrait combination, have a great advantage in this respect. The Harvard College Observatory has been using portrait lenses of eight inches aperture and forty-four inches focus for this purpose, and is now making a similar lens of twenty-four inches aperture and eleven feet focus. Reflectors are very suitable also, and, in my opinion, the next great telescope for photography should be a reflector of large aperture and short focus. Mr. Common, of London, has just

mounted a five-foot reflector of this class, and its performance will be eagerly watched, in order to see what work is to be expected from instruments of this construction.

If stars are to be taken as dots, the clock must follow the motion of the stars very accurately, or else the telescope (or the photographic plate) must be moved by hand from time to time, to correct the irregularities of the clock-work motion and the small changes in the star's apparent position, due to refraction, etc.

In the Lick telescope, the photographic focus is forty-seven feet six inches. The slightest wandering of the axis of the telescope, or the slightest flexure of the tube, etc., will produce a comparatively great displacement of the image on the plate.

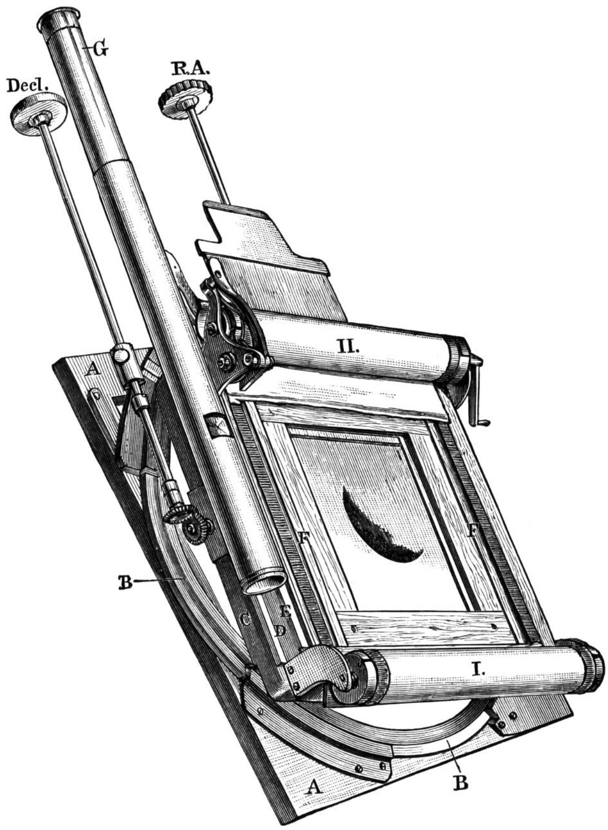
Our driving-clock is electrically controlled from a standard clock, so that it goes at precisely the right rate. But we still find it necessary to move the plate by hand (by means of two screws at right angles to each other), to correct the minor irregularities of the train beyond the clock, refraction, flexure, etc. A guiding eye-piece is attached to the plate itself, and a guiding star is kept exactly at the intersection of two wires in the eye-piece, by moving a slide which carries both plate and eye-piece. (See the accompanying plate.)

Such a long-focus telescope as ours cannot produce maps of the faintest stars as easily as such maps can be made by shorter-focused instruments. On the other hand, we have an immense advantage in the scale of the picture. $1''$ of arc $=$ 0.003 inches; $0''.01 =$ 0.00003 inches. It is easy to measure the distance apart of two dots or trails (under a suitable microscope) correctly to $0''.03$ or so. Hence, the relative positions of stars (or of craters on the moon, etc.) can be accurately and quickly fixed from our negatives.

To detect shrinkage of the film, we impress the image of a reticle ruled in squares on the negative before exposure, and, on development, we have these squares displayed. A comparison of the squares of the reticle with the squares of the negative will detect distortions of the film, etc. For accurate measures our negatives must be made on plate glass. The beautiful reticles which we have were ruled at the Potsdam Observatory by Professor H. C. VOGEL and Dr. SCHEINER.

Thus, wherever scale is of importance, as for measures of parallax, etc., the great telescope has a decided advantage over shorter-focused telescopes. A distance of $2000''$ to $3000''$ of arc can be measured with a probable error of not more than $0''.1$ or $0''.2$.

Trails of stars can be used to measure differences of declination



COMPOUND SLIDE-REST FOR CARRYING THE NEGATIVE PLATE OF THE THIRTY-SIX-INCH EQUATORIAL.

(By the courtesy of the Council of the Royal Astronomical Society.)

The mechanical parts made by WARNER & SWASEY; the optical by J. A. BRASHEAR.

The frame A A is fixed in the tube at right angles to the optical axis. The frame D and everything above is movable in declination by the handle Decl.; the frame E and the eye-piece G are movable in right-ascension by the handle R.A. The guiding eye-piece G receives a beam from the object-glass, and the image of a star is kept on its cross-wires by suitably moving the handles. The wires are lighted by a small incandescent lamp. The plate-holder shown in the cut is 8×10; the image of the moon is about five inches in diameter. I and II are curtains on spring rollers, for quick exposures. The two handles and the end of G project several inches outside of the telescope tube.

(perpendicular to the trails), and thus to determine parallax, etc. Trails are also suitable for measures of the photographic brightness of stars. For this purpose, it seems best to give all stars the same exposure, and this can be effected (as suggested by Mr. SCHAEBERLE of the Lick Observatory) by causing the plate to follow the stars in right ascension, but to trail in declination; that is, to make the stars impress themselves on a plate which follows their motion from east to west, but which is also driven by a second clock-work at a uniform rate from north to south. Every star sufficiently bright can thus be compared with *Polaris*, and the photographic brightness of each star, in terms of that of *Polaris* as unity, can be deduced. The same thing can be (less accurately, I think,) determined by measuring the diameter of the images of the various stars, and by comparing the diameters of the various stars with that of *Polaris* on the same plate.

The subject of photographic photometry is a very difficult one, both theoretically and practically, and involves a knowledge of the relation between the intensity of the stain on the plate and the exposure time. Captain ABNEY, whose authority is of the highest, has come to the conclusion that "the deposit of silver made by different intensities of light, varies in density* directly as the intensity of light acting—this, of course, within such limits that the reversal of the image is not commenced, and that the film is not in any part exhausted of the silver salt that can be reduced." Our own experiments on this subject (which are just begun) seem to indicate a somewhat less general conclusion.

As the question is fundamental, it may not be improper to give the conclusions we have so far attained, with the proper reserve, since further experiment may modify the results now apparently reached. For a light of a given intensity, I, for example, it seems to follow from our work, that for very short exposures the density of the deposit D increases very much faster than directly as the time, T. For longer exposures, the density D′ becomes more nearly proportional to T′; for still longer exposures, the proportion again falls off, long before the halation stage is reached.

Thus, for light of intensity, I, we have from zero to T; D varies more rapidly than directly as the time; from T′ to T″, D varies as the time; from T″ to T‴, D varies less rapidly than directly as the time. For light of intensity, *i*, the density *d* goes through these three stages of different intervals $t' - o$; $t'' - t'$; $t''' - t''$.

A very important point seems to be that t' is not the same as T′;

* I understand this to mean "varies in opacity," though I may misinterpret the expression.

t'' not the same as T'', etc., but that t varies with i. That is, if the deposit on a given plate is proportional to the time, between five seconds and ten seconds, for example, for a light, i, it will not be proportional to the time between these limits for a light of greater intensity, I. For I, it may be so proportional between other limits of exposure, as three seconds and seven seconds and so on.

If these results are true, they seriously modify photometric conclusions hitherto reached by means of photography.

I have been willing to speak at this time of experiments which are still in progress, and whose results are by no means final, on account of the great importance of this question, and in the hope of inciting others to experiments on the same subject.

Mr. SCHAEBERLE has found that if d be the diameter of a star-image (dot) taken with a six-inch DALLMEYER portrait lens in a time t on a Seed 26 plate, with a diaphragm Q inches in aperture in front of the objective, that we can express this diameter as follows:

$$d = \mathrm{A} + \mathrm{B} \log \mathrm{Q} + \mathrm{C} \,.\, \mathrm{Q} \,.\, \log t.$$

A, B and C are constants which must be determined for each plate. It is probable, though not proved as yet, that this equation is only true between certain limits i, and I, of intensity of star light, and between certain limits t, and T, of exposure time. It has served very well to predict the diameter of over-exposed stars.

PHOTOGRAPHS OF SOLAR ECLIPSES.

The solar eclipse of January 1, 1889, occurred soon after the observatory was founded, and before suitable photographic instruments were available. Nevertheless, Mr. BARNARD contrived to take most capital negatives with some small cameras, and especially with an ordinary telescope of three inches aperture (reduced to 1¾ inches) and a focus of forty-nine inches. (Seed 26 plates were used, and exposures of 1, 3 and 4½ seconds.) The greatest pains were taken in focusing and in development, and his results are consequently of first-class excellence, and comparable with those obtained by much larger instruments, specially adapted for photography.

The Amateur Photographic Association of the Pacific Coast sent a large and competent party to the eclipse, under the direction of Mr. BURCKHALTER, and their negatives were kindly turned over to the Lick Observatory for discussion and publication. At this eclipse not only was the Corona thoroughly depicted, but the negatives of Mr. BARNARD of the Observatory, and of Messrs. LOWDEN and IRELAND of the A. P. A. P. C. (and many others) showed a new and

very remarkable extension to the outer Corona, never before photographed. As this "extension" was shown on several negatives taken by eleven persons at four different stations, there seems to be no question as to its veritable existence.

The expedition sent from the Lick Observatory at the cost of Hon. C. F. CROCKER, to observe the eclipse of December, 1889, was likewise fully successful. Both Mr. BURNHAM and Mr. SCHAEBERLE secured a number of capital photographs of the Corona. Their reports on this eclipse are not yet completed, and therefore I must content myself with a mere reference to them in this place. My own measures of their negatives are given in the table below.

Following the suggestion of Captain ABNEY and the example of Mr. W. H. PICKERING, of the Harvard College Observatory, the Lick Observatory plates were "standardized." That is, a portion of each plate was impressed with the light from a standard lamp, shining for a known time through a small hole at a known distance. The lamp produced small squares on the plates, and after development these squares were compared with the different parts of the Corona, in in order to measure the photographic brightness.

Assuming with Captain ABNEY that the stain on the plate is proportional to the exposure, I found the following results, which are compared with those of Mr. PICKERING in 1886:

	PICKERING—1886.	HOLDEN—Jan. 1889.	HOLDEN—Dec. 1889.
Intrinsic actinic brilliancy of the brightest parts of the Corona....	0.031	0.079	0.029
Intrinsic actinic brilliancy of the polar rays (about).....................	....	0.053	0.016
Intrinsic actinic brilliancy of the sky near Corona.....................	0.0007	0.0050	0.0009
Total actinic light of the Corona.....	37.	60.8	26.2
Total actinic light of the sky........	52000.	185625.	33412.
Ratio of total coronal to total sky light (actinic)......	1 to 1400	1 to 3043	1 to 1285
Ratio of intrinsic brilliancy of the brightest parts of the Corona to that of the sky (actinic)...............	44 to 1	16 to 1	32 to 1
Intrinsic actinic brilliancy of the sky at 1° from the sun in daylight (average).......................	40.	....	....
Intrinsic actinic brilliancy of the full moon..........................	1.66	....	....
Total actinic light of the full moon (SD = 16′.75)..................	1461.5	....	....
Intrinsic actinic brilliancy of sky within 5° of the full moon...............	0.000064	....	....
Magnitude of the faintest star shown on the eclipse photographs........	....	2.3	....

From this table (Column II) it appears that the polar rays are about eleven times as bright as the sky; and that the brightest parts of the Corona are one and one-half times as bright as the polar rays. Hence, these are usually masked when they are projected upon the bright wings.

The intrinsic brilliancy of sunlight *plus* Corona (40.08) is $\frac{1}{500}$ part more than the brilliancy of the ordinary daylight 1° from the sun (40.0). Hence it would seem that the Corona (which has a continuous spectrum) can never be photographed in full daylight on our present plates.

As the planet *Vulcan* (?) (if any such planet exists) is not brighter than sixth magnitude, it follows that we cannot hope to photograph it on our present plates.

The corresponding results from the eclipse of December 21, 1889, are given in Column III. For reasons which I have given elsewhere I think the results in Column II are to be preferred to those in Columns I and III in spite of their agreement.

Photographs of the Moon.

Our first experiments in photography with the large telescope were made by Mr. Burnham, on the moon. As no suitable shutter was then available, the aperture was reduced to twelve and eight inches to increase the exposure time.

The best of these experimental pictures are very fine. Enlargements of them have been made on glass by Mr. Barnard, and I have been able to locate the minutest details of structure on these positives. Parallel walls on the moon, whose tops are no more than two hundred yards or so in width, and which are not more than 1,000 to 1,200 yards apart, are plainly visible.

In the examination of such pictures there is an immense advantage in using a positive copy on glass (which presents the different features in their natural lustre) rather than the original negative. The same thing is true of pictures of solar eclipses.

In certain negatives many details can be brought out by enlargement, or by reductions, that entirely escape notice on the originals.

Photographs of the Milky Way.

Mr. Barnard made some experiments in this direction in 1889, which promise the most satisfactory results. The instrument used was a five-inch portrait lens, and the exposures were 180 to 240 minutes.

It is proposed to photograph the whole of the Milky Way on one scale and with one exposure in this manner.

Photographs of Nebulæ and Comets.

Very little has yet been done here in these important fields. A few nebulæ have been photographed for experiment, with good results. Mr. Barnard photographed Davidson's comet, with a portrait lens and an exposure of ninety minutes. I have compared the brightness of the comet with that of the stain on the same plate derived from the light of a standard lamp shining for a known time on the film. If the conclusion of Capt. Abney, namely, that the stain on the plate is proportional to the time, is correct, then it followed that the comet was 10,000,000 times fainter than the full moon, area for area, and that it was 500,000 times fainter than the brightest parts of the Corona of January 1, 1889. The sky near the full moon is also, on the same hypothesis, 400 times more bright (photographically) than the comet, and 4,000 times more bright than the dark night sky.

Mr. Barnard's photographs of the nebula of *Andromeda*, with a portrait lens, are highly interesting and important, but we have as yet obtained no pictures of nebulæ which are as striking as the wonderfully fine impressions of the *Merope* nebula, of that in *Andromeda*, or of the great nebula in *Orion*, made by Messrs. Henry, Roberts and Common, and by the Harvard College Observatory.

The excellence of the great telescope will not be shown by extremely great extension of faint nebulæ, but rather by the very large scale on which these objects are taken. It has its own appropriate field, and within that field it promises admirable results. Many vexatious hindrances have occurred in making this great instrument ready for photographic use, but it is hoped that during the summer of 1890 it may be in full activity.